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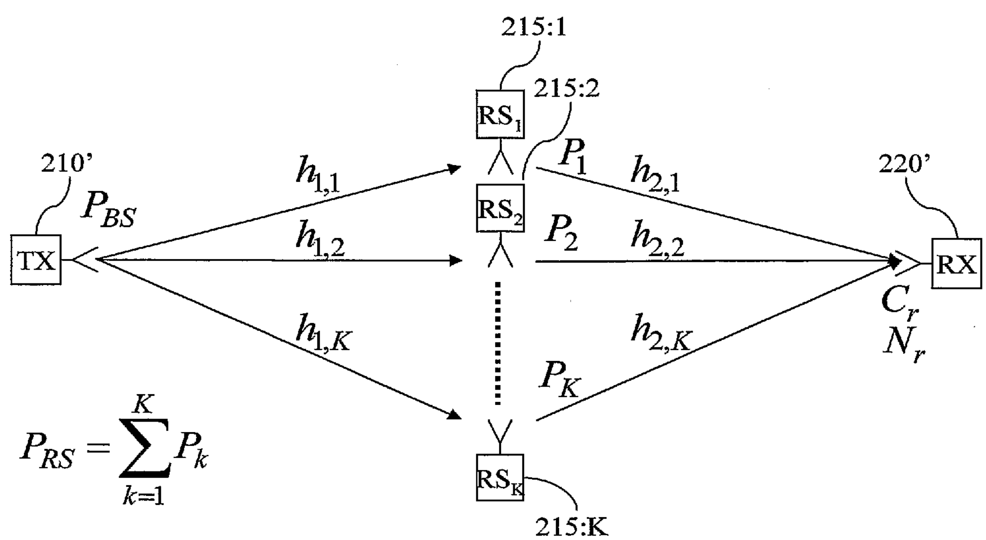
(54) **Title:** METHOD AND SYSTEM FOR WIRELESS COMMUNICATION NETWORKS USING RELAYING



(57) **Abstract:** The present invention relates to wireless networks using relaying. In the method according to the present invention of performing communication in a two-hop wireless communication network, a transmitter 210, a receiver 220 and at least one relay station 215 are engaged in a communication session The relay station 215 forwards signals from a first link between the transmitter 210 and the relay station 215 to a second link between the relay stations 215 and the receiver 220. The forwarding performed by the at least one relay station 215 is adapted as a response to estimated radio channel characteristics of at least the first link. Preferably the forwarding is adapted as a response to estimated radio channel characteristics of both the first and second link.

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Method and system for wireless communication networks using relaying

Field of the invention

The present invention relates to relay supported wireless communication to enhance communication performance. In particular the invention relates to a method and a system for performing communication in a two-hop wireless communication network

Background of the invention

A main striving force in the development of wireless/cellular communication networks and systems is to provide, apart from many other aspects, increased coverage or support of higher data rate, or a combination of both. At the same time, the cost aspect of building and maintaining the system is of great importance and is expected to become even more so in the future. As data rates and/or communication distances are increased, the problem of increased battery consumption is another area of concern.

Until recently the main topology of wireless networks has been fairly unchanged, including the three existing generations of cellular networks. The topology characterized by the cellular architecture with the fixed radio base stations and the mobile stations as the transmitting and receiving entities in the networks, wherein a communication typically only involves these two entities. An alternative approach to networks are exemplified by the well-known multihop networks, wherein typically, in a wireless scenario, a communication involves a plurality of transmitting and receiving entities in a relaying configuration. Such systems offer possibilities of significantly reduced path loss between communicating (relay) entities, which may benefit the end-to-end (ETE) users.

Attention has recently been given to another type of topology that has many features and advantages in common with the multihop networks but is limited to only two (or a few) hop relaying. In contrast to multihop networks, aforementioned topology exploits aspects of parallelism and also adopts themes from advanced antenna systems. These networks, utilizing the new type of topology, have cooperation among multiple stations as a common denominator. In recent research literature, it goes under several names, such as cooperative relaying, cooperative diversity, cooperative coding, virtual antenna arrays, etc. In the present application the terms “cooperative relaying” and “cooperative schemes/methods” is meant to encompass all systems and networks utilizing cooperation among multiple stations and the

schemes/methods used in these systems, respectively. A comprehensive overview of cooperative communication schemes are given in [1]. Various formats of a relayed signal may be deployed. A signal may be decoded, re-modulated and forwarded, or alternatively simply amplified and forwarded. The former is known as decode-and-forward or regenerative relaying, whereas the latter is known as amplify-and-forward, or non-regenerative relaying. Both regenerative and non-regenerative relaying is well known, e.g. by traditional multihopping and repeater solutions respectively. Various aspects of the two approaches are addressed in [2].

The general benefits of cooperative relaying in wireless communication can be summarized as higher data rates, reduced outage (due to different forms of diversity), increased battery life, extended coverage (e.g. for cellular).

Various schemes and topologies utilizing cooperative relaying has been suggested, as theoretical models within the area of information theory, as suggestions for actual networks and in a few cases as laboratory test systems, for example. Examples are found in [1] pages 37-39, 41-44. The various cooperation schemes may be divided based on which entities have data to send, to whom and who cooperates. In FIGs. 1a-f (prior art) different topologies are schematically illustrated, showing where traffic is generated, who is the receiver and the path for radio transmissions.

The classical relay channel, illustrated in FIG. 1a, consists of a source that wishes to communicate with a destination through the use of relays. The relay receives the signal transmitted by the source through a noisy channel, processes it and forwards it to the destination. The destination observes a superposition of the source and the relay transmission. The relay does not have any information to send; hence the goal of the relay is to maximize the total rate of information flow from the source to the destination. The classical relay channel has been studied in [1], [7]and in [3] where receiver diversity was incorporated in the latter. The classical relay channel, in its three-station form, does not exploit multiple relay stations at all, and hence does not provide the advantages stated above.

A more promising approach, parallel relay channel, is schematically illustrated in FIG 1b, wherein a wireless systems employing repeaters (such as cellular basestation with supporting repeaters) with overlapping coverage, a receiver may benefit of using super-positioned signals received from multiple repeaters. This is something that happens automatically in systems when repeaters are located closely. Recently, information theoretical studies have addressed

this case. A particular case of interest is by Schein, [4] and [5]. Schein has performed information theoretical study on a cooperation-oriented network with four nodes, i.e. with one transmitter, one receiver and only two intermediately relays. A real valued channel with propagation loss equal to one is investigated. Each relay employs non-regenerative relaying, i.e. pure amplification. Thanks to the simplistic assumption of real valued propagation loss, the signals add coherently at the receiver antenna. Under individual relay power constraints, Schein also indicates that amplification factors can be selected to maximize receiver SNR, though does not derive the explicit expression for the amplification factors. One of the stations sends with its maximum power, whereas the other sends with some other but smaller power. The shortcoming of Schein's schemes is that it is; only an information theoretical analysis, limited to only two relay stations, derived in a real valued channel with gain one (hence neglecting fundamental and realistic propagation assumptions), lacks the means and mechanisms to make the method practically feasible. For example, protocols, power control and RRM mechanisms, complexity and overhead issues are not addressed at all. With respect to only addressing only two relay stations, the significantly higher antenna gains and diversity benefits, as would result for larger number of relays, are neither considered nor exploited.

The concept of Multiple-access Channel with Relaying (a.k.a. as Multiple access channels with generalized feedback) has been investigated by several researchers lately and is schematically illustrated in FIG. 1c. The concept involves that two users cooperate, i.e. exchange the information each wants to transmit, and subsequently each user sends not just its own information but also the other users information to one receiver. The benefit in doing so is that cooperation provides diversity gain. There are essentially two schemes that have been investigated; cooperative diversity and coded cooperative diversity. Studies are reported in [1], for example. With respect to diversity, various forms has bee suggested, such as Alamouti diversity, receiver diversity, coherent combining based diversity. Typically the investigated schemes and topologies rely on decoding data prior to transmission. This further means that stations has to be closely located to cooperate, and therefore exclude cooperation with more distant relays, as well as the large number of potential relays if a large scale group could be formed. An additional shortcoming of those schemes is that is fairly unlikely having closely located and concurrently transmitting stations. These shortcomings indicates that the investigated topology are of less practical interest. The broadcast channel with relaying, illustrated in FIG. 1d, is essentially the reverse of the topology depicted in FIG 1c, and therefore shares the same severe shortcomings.

A further extension of the topology depicted in FIG. 1c is the so-called interference channel with relaying, which is illustrated in FIG. 1e, wherein two receivers are considered. This has e.g. been studied in [8] and [1] but without cooperation between the receivers, and hence not exploiting the possibilities possibly afforded by cooperative relaying.

Another reported topology, schematically illustrated in FIG. 1f, is sometimes referred to as Virtual Antenna Array Channel, and described in for example [9]. In this concept, (significant) bandwidth expansion between a communicating station and adjacent relay nodes is assumed, and hence non-interfering signals can be transferred over orthogonal resources that allows for phase and amplitude information to be retained. With this architecture, MIMO (Multiple Input Multiple Output) communication (but also other space-time coding methods) is enabled with a single antenna receiver. The topology may equivalently be used for transmission. A general assumption is that relay stations are close to the receiver (or transmitter). This limits the probability to find a relay as well as the total number of possible relays that may be used. A significant practical limitation is that very large bandwidth expansion is needed to relay signals over non-interfering channels to the receiver for processing.

Cooperative relaying has some superficial similarities to the Transmit diversity concept in (a.k.a. Transmit diversity with Rich Feedback, TDRF), as described in [10] and is schematically illustrated in FIG. 1g. Essential to the concept is that a transmitter with fixed located antennas, e.g. at a basestation in a cellular system, finds out the channel parameters (allowing for fading effects and random phase) from each antenna element to the receiver antenna and uses this information to ensure that a (noise free) signal, after weighting and phase adjustment in the transmitter, is sent and adds coherently at the receiver antenna thereby maximizing the signal to noise ratio. While transmit diversity, with perfectly known channel and implemented in a fixed basestation, provides significant performance benefits, it also exist practical limitations in terms of the number of antenna elements that can be implemented in one device or at one antenna site. Hence, there is a limit in the degree of performance gain that can be attained. A disadvantage for basestation oriented transmit diversity is also that large objects between transmitter and receiver incur high path loss.

Thus, it is in the art demonstrated that cooperative relaying have great potentials in providing high capacity and flexibility, for example. Still, the in the art proposed topologies and methods do not take full advantage of the anticipated advantages of a network with cooperative relaying.

Summary of the invention

In the state of the art methods, the quality of the first link, the second link or a combination thereof is not considered in adapting any transmission parameters. This has the consequence that performance may degrade and resources are inefficiently utilized.

Hence, a significant shortcoming of the above discussed prior art is that they do not adapt transmit parameters of the relays in response of the quality of a link or combination of links (first and second) involved in the forwarding procedure. Whereby, the prior art has not been able to fully take advantage of the anticipated advantages of a cooperative relaying network.

Obviously an improved method and system for a cooperative relaying network is needed, which consider the quality of the first link, the second link or a combination thereof in adapting transmission parameters is needed, to whereby have the ability to better take advantage of the anticipated advantages of a cooperative relaying network.

The object of the invention is to provide a method, a relay station and a system that overcomes the drawbacks of the prior art techniques. This is achieved by the method as defined in claim 1, the relay station as defined in claim 12 and the system as defined in claim 16.

The problem is solved by that the present invention provides a method, a relay station and a system that makes it possible to use estimated radio channel characteristics of both the first and second link for adapting the forwarding of signals from a first link to a second link performed by the relay station.

In the method, according to the present invention of performing communication in a two-hop wireless communication network, a transmitter, a receiver and at least one relay station are engaged in a communication session. The relay station forwards signals from a first link between the transmitter and the relay station to a second link between the relay stations and the receiver. The forwarding performed by the at least one relay station is adapted as a response to estimated radio channel characteristics of at least the first link. Preferably the forwarding is adapted as a response to estimated radio channel characteristics of both the first and second link.

The relay station according to the present invention is adapted for use in a two-hop wireless communication network, wherein the network comprises a transmitter, a receiver and at least one relay station. The relay station is adapted to forward signals from a first link between the

transmitter and the relay station to a second link between the relay stations and the receiver. The relay station is provided with means for adapting the forwarding based on characterization of both the first and second link.

Thanks to the invention it is possible to better adjust the forwarding on the second link to the actual conditions present during a communication session. In addition the forwarding can be better adjusted to changes in the conditions.

One advantage afforded by the present invention is that the more precise and reliable characterization of the individual radio paths may be used to determine and optimize different transmission parameters. Whereby, the capabilities of a cooperative relaying network, for example, may be more fully exploited.

A further advantage is that characterisation of the first and second link advantageously is performed in the relay stations. Hence, the method according to the invention fascilitates a distribution of functionalities in the network allowing an increase in the number of relay stations in a communication session without any significant increase in the amount of protocol overhead that is needed for the transmission of data from the transmitter to the receiver.

A yet further advantage further advantage of the method and system according to the present invention is that the improved characterization of the first and second link facilitate to take full advantage of the anticipated advantages of a network with cooperative relaying that comprises a larger number of relaying stations. With the invention used in a coherent combining setting, the directivity gain and diversity gain increases with increasing number of relay stations. The directivity gain itself offers increased SNR that can be used for range extension and/or data rate enhancement. The diversity gain, increases the robustness of the communication, providing a more uniform communication quality over time. While directivity and diversity gain can be provided by various traditional advanced antenna solutions, where the antennas are placed either at the transmitter or the receiver, the proposed solution is generally not limited to the physical space constraints as is seen in basestations or mobile terminals. Hence, there is indeed a potential to use a larger number of relays, than the number of antennas at a basestation or a mobile station, and hence offer even greater directivity and diversity gains.

Embodiments of the invention are defined in the dependent claims. Other objects, advantages and novel features of the invention will become apparent from the following detailed

description of the invention when considered in conjunction with the accompanying drawings and claims.

Brief description of the figures

The features and advantages of the present invention outlined above are described more fully below in the detailed description in conjunction with the drawings where like reference numerals refer to like elements throughout, in which:

Fig. 1a-g are schematic illustrations of the topologies of some prior art utilizing cooperative relaying;

Fig 2. schematically illustrates a cellular system using cooperative relaying according to the present invention;

Fig. 3 is a schematic model used to describe the parameters and terms used in the present invention;

Fig. 4 is a flowchart over the method according to the invention;

Fig. 5a and 5b are a schematic illustrations of two alternative logical architectures for the cooperative relaying network according to the present invention;

Fig. 6 is a flowchart over one embodiment of the method according to the invention;

Fig. 7 is a schematic illustration of an alternative embodiment of the invention utilizing relay stations with multiple antennas;

Fig. 8 is a schematic illustration of an alternative embodiment of the invention utilizing direct transmission between the transmitter and the receiver;

Detailed description of the invention

Embodiments of the invention will now be described with reference to the figures.

The network outlined in FIG. 2 is an example of a cooperative relaying network wherein the present invention advantageously is implemented.. The figure shows one cell 205 of the wireless network comprising a basestation 210 (BS), a plurality of relay stations 215 (RS) and a plurality of mobile stations (MS) 220-223. As shown in the figure, the relay stations 215 are mounted on masts, but may also be mounted on buildings, for example. Fixed relays may be used as line of sight conditions can be arranged, directional antennas towards the basestation may be used in order to improve SNR (Signal-to-Noise Ratio) or interference suppression and the fixed relay may not be severely limited in transmit power as the electricity supply network

typically may be utilized. However, mobile relays, such as users mobile terminals, may also be used, either as a complement to fixed relays or independently. The mobile stations 221 and 222 are examples of mobile relays, i.e. mobile stations that temporarily functions also as relays. The mobile station 220 is in active communication with the base station 210. The signalling, as indicated with arrows, is essentially simultaneously using a plurality of paths, characterized by two hops, i.e. via a relay station 215 or a mobile station acting as a mobile relay 221, 222. The transmission will experience interference from for example adjacent cells, and the effect of the interference will vary over the different paths.

It should be noted that although relay based communication is used to enhance communication, direct BS to MS communication may still be used. In fact, some basic low rate signalling between BS and MS may be required for setting up a relay supported communication channel. For example, a cellular system function such as paging may not use coherent combining based relaying as the relay to MS channels are not a priori known, instead preferably, a direct BS to MS communication is used during call setup and similar procedures.

The real world cellular system outlined in FIG. 2 is modeled by system model shown in FIG. 3, here with focus on a single pair of transmitter and receiver, with an arbitrary number K of relay stations. The notation is adapted to a basestation 210 as a transmitter and a mobile station 220 as a receiver, but not limited thereto. The communication between the basestation 210 and the mobile station 220 can be described as comprising two main parts: the transmissions from the base station 210 to the relay stations 215:k referred to as Link 1, and the transmissions from the relay stations 215:k to the mobile station 220 referred to as Link 2.

The transmitter, i.e. BS 210 transmits with a power P_{BS}. Each relay station 215:k, wherein $k \in \{1,2,\ldots,K\}$ and K is the total number of relay stations, receive the signal and re-transmits with a total power P_k. The aggregate transmit power of all relay stations 215:k is denoted P_{RS}. $h_{1,k}$ is the complex path gain from the basestation 210 to relay station k 215:k, and $h_{2,k}$ is the complex path gain from the relay station k to the mobile station, i.e. $h_{1,k}$ and $h_{2,k}$ characterizes the individual signal paths. The receiver, i.e. MS 220, receives a total signal denoted C_r and experience the total noise N_r.

Typically, in a realistic scenario a BS in a cell is simultaneously engaged in communication with a plurality of mobile stations. This can be envisaged by considering each communication as modeled in accordance to FIG. 3. For clarity only a communication session involving one

BS, one MS and a plurality of relay station will be considered in the present application. However, as will be apparent for the skilled in the art the inventive architecture and method/scheme is easily applied also in the case with a plurality of simultaneous communications between the base station and mobile stations.

As realized by the skilled in the art, in a network according to the above model, a large number of parameters need to be set and preferably optimized in order to fully take advantage of the possibilities and capacity offered by such a network. This is also, as previously discussed, there the prior art systems display their shortcomings as multi-relay systems, due to their presumed complexity, are not discussed. Parameter that needs to be considered and preferably optimized include, but is not limited to, transmit power of the basestation 210 and each relay station 215:*k*, which relay stations that should be used in the communication, phase control (if coherent combining is used), coding, delay (in the case of delay diversity), antenna parameters (beamforming, spatial multiplexing), etc. The parameters needed to control and optimize the transmission will be referred to as transmission parameters (TP). A preferred optimization includes, but is not limited to, optimizing the transmit powers of the base station 210 and the relay stations 215:*k* in order to obtain a specific SNR at the receiving mobile station, which in turn correspond to a certain quality of service or capacity, for example, with regards to power consumption of the different entities and the interference level in the cell and adjacent cells, for example.

Fundamental to all optimization and necessary for an efficient use of the radio recourses is an accurate characterization of the radio paths in the first and second link, and control over how any changes in any transmission parameter will affect the overall performance. The method according to the present invention provides a method wherein a relay station 215:*k* uses channel characteristics of both the first and second link to determine transmission parameters for the forwarding on the second link. In addition, according to the method, each relay station 215:*k* may optionally adapt its forwarding on the second link to a quality measure on the communication in full as perceived by the receiver 220, for example. The quality measure on the communication in full will be referred to as the common transmission parameter.

In the method according to the present invention of performing communication in a two-hop wireless communication network, a transmitter 210, a receiver 220 and at least one relay station 215 are engaged in a communication session The relay station 215 forwards signals from a first link between the transmitter 210 and the relay station 215 to a second link between the relay stations 215 and the receiver 220. The forwarding performed by the at least

one relay station 215 is adapted as a response to estimated radio channel characteristics of at least the first link. Preferably the forwarding is adapted as a response to estimated radio channel characteristics of both the first and second link.

The method according to the invention will be described with reference to the flowchart of FIG. 4 The method comprises the main steps of:

400: Send pilots on the *k* paths of link 1;

410: Characterize the *k* paths of link 1.

420: Send pilots on the *k* paths of link 2;

430: Characterize the *k* paths of link 2.

440: Determine relative transmission parameters for each relay station 215, wherein each relative parameter is based on the characterization of the respective paths of link 1 or a combination of link 1 and link2.

450: Each relay station 215:*k* adapts the forwarding on link 2 to the receiver 220 using its respective relative transmission parameter.

Optionally the method comprises the step of:

445: Determining a common transmission parameter reflecting the quality of the communication in full.

447: Distribute the common transmission parameter to the relay stations (215).

and step 450 is subsequently replaced with:

450': Each relay station 215:*k* adapts the forwarding on the second link to the receiver 220 using its respective relative transmission parameter and the common transmission parameter.

"Pilots" and "sending pilots" should be interpreted as sending any kind of channel estimation symbols. "Hello messages" may also be used for this purpose.

It should be noted that the sending of pilots does not have to occur in the above order and may also be simultaneous on link 1 and 2.

The characterization of the radio paths in steps 410 and 430 is preferably adapted to the transmission technique used, and possibly also to the type of optimization which should utilize the characterization. The characterization may comprises of, but is not limited to:

estimating complex path gains $h_{1,k}$ and $h_{2,k}$ characterizing each path of the first and second link, respectively.

As there are two links, transmitter to relay and relay to receiver, there are four possibilities of which station(s) transmit and which station(s) estimate the channel(s). The four possibilities are summarized in Table 1. The purpose is to illustrate that several different implementation approaches of the invention may be taken.

Case	Link 1		Link 2	
	Transmitter	Relay	Relay	Receiver
1	Send pilot	Estimate ch.	Estimate ch.	Send pilot
2	Send pilot	Estimate ch.	Send pilot	Estimate ch.
3	Estimate ch.	Send pilot	Estimate ch.	Send pilot
4	Estimate ch.	Send pilot	Send pilot	Estimate ch.

Table 1

Given that channel estimation has been performed in some station, it is also an issue who perform processing of the collated information, i.e. determine the relative transmission parameters. Essentially, there are three choices, the transmitter BS 210, the receiver MS 220 or a set of relay stations RS 215. Since it is the relay stations that must perform the adjustments of the forwarding on link 2, this is the preferred place to determine the relative transmission parameters. If a relay station sends a pilot signal, a representation of the channel characterization needs to be reported back to the relay. If a relay station instead receives a pilot, the representation of the channel characterization does not need to be reported anywhere (corresponding to case 1). Case one is in many situations the preferred alternative, since it minimizes the overhead signalling. On the other hand, one may want to keep the relay stations as simple as possible and perform all calculations in the receiver and/or transmitter, or in entities in connection with the receiver or transmitter. If, so case 4 of table1 may be preferred, and all estimation and calculation is performed in other entities than the relay stations. The information needed for the relay stations to adjust their respective forwarding is sent to each relay station. As illustrated, many possible combinations exist and the invention is not limited to a specific one.

A preferred system according to the invention, adapted to be able to effectuate the above-described case 1, will be described with reference to FIG. 5a. Each relay station 215:k has means for performing channel characterization 216 and means for determining relative transmission parameters 217 based on the channel characterization and means for adjusting 218 the forwarding based on relative transmission parameters and optionally on a common transmission parameter. The receiver 220 has means for performing a quality measure of the collective signal 221 and optionally means for determining a common transmission parameter 222. The common transmission parameter is distributed from the receiver 220 to the relay stations 215:k either as a direct broadcast to the relay stations 215:k or via the transmitter 210. The relay stations 215:k receive the common transmission parameter and in combination with their relative transmission parameters adjust their forwarding of the signal. This can be seen as comprising a logical control loop between the receiver 220 and the relay stations 215:k. Typically another logical control loop exists between the receiver 220 and the transmitter 210, regulating the transmitter's transmission parameters such as output power, modulation mode etc. Hence, the preferred embodiment of the present invention comprises two logical control loops: a first control loop 505 between the receiver 220 and the relay stations 215:k, providing the relay stations with the common transmission parameter, and a second control loop 510 feed-backing transmission information from the receiver 220 to the transmitter 210.

In an alternative embodiment, adapted to be able to effectuate the above described cases 3-4, and described with reference to FIG. 5b., the means for performing channel characterization 216 and means for determining both the relative transmission parameters 217 and the common transmission parameters 222 is centralized located in the receiver 220, for example. The receiver receives the unprocessed results of the pilot from the relay station 215 and/or transmitter 210. The receiver performs the necessary estimations and sends information on the relative transmission parameters and the common transmission parameter to the relay stations 215, either as a broadcasted message including all relative transmission parameters or as dedicated messages to each relay station. Alternatively may the transmitter perform the estimation of the radio paths of the first link (case 2), and hence, have the means therefore. A further alternative is that the characterization and the determination of transmission parameters is performed However, preferably the receiver and transmitter communicate to present a collected message, or messages, with all transmission parameter information to the relay stations, either as a broadcasted message to all relay stations or as dedicated messages to each relay station. A further alternative is that the characterization and the determination of

transmission parameters is performed elsewhere in the network, for example in a radio network controller (RNC) or an entity with similar functionality.

As described the present invention makes it possible to more precise and reliable determine and optimize different transmission parameters. This is turn makes it possible to fully take advantage of the capabilities of a relaying network, in particular the capabilities of a cooperative relaying network.

The method according to the invention facilitates a distribution of functionalities in the network allowing an increase in the number of relay stations in a communication session without any significant increase in the amount of protocol overhead that is needed for the transmission of data from the transmitter to the receiver.

To efficiently implement the method according to the above, a procedure of taking the characterization of the radio paths of both the links, and possibly common quality measures, into account in determining the forwarding parameters is desirable. An efficient procedure is outlined below and a full derivation of included expressions "derivation of analytic expressions" is given at the end of the detailed description. How the procedure can be adapted to control and optimize transmitted power, phase and relay station activation, representing different embodiments, is also given below.

Each relay station k transmits with a total power defined by

$$P_k = \frac{P_{RS} \cdot |a_k|^2}{\sum_{k=1}^{K} |a_k|^2} \tag{1}$$

,where P_{RS} is the aggregate transmit power of all relay stations, a_k is a un-normalized complex gain factor for relay station $k \in \{1,2,\ldots,K\}$ and K is the total number of relay stations.

In "derivation of analytic expressions" it is shown that the maximum receiver SNR is attained (provided received signal is normalized to unit power) if

$$|a_k| = \frac{\sqrt{\Gamma_{RS,k}} \cdot \sqrt{\Gamma_{MS,k}} \cdot \sqrt{\Gamma_{RS,k} + 1}}{\Gamma_{RS,k} + \Gamma_{MS,k} + 1} \tag{2}$$

, and if

$$\arg\{a_k\} = -\arg\{h_{1,k}\} - \arg\{h_{2,k}\} \tag{3}$$

where

$$\Gamma_{RS,k} = \frac{|h_{1,k}|^2 P_{BS}}{\sigma_{RS,k}^2}$$

,and

$$\Gamma_{MS,k} = \frac{|h_{2,k}|^2 P_{RS}}{\sigma_{MS}^2}$$

,and P_{BS} is the transmit power of the basestation, $\sigma_{RS,k}^2$ is the noise plus interference level at any relay station, σ_{MS}^2 is the noise level at the mobile station, $h_{1,k}$ is complex path gain from the basestation to relay station k, and finally $h_{2,k}$ is complex path gain from the relay station k to the mobile station.

It is can be shown (see the detailed derivation) that a relay station k that receives a signal y_k shall transmit the following signal

$$z_k = y_k \cdot \frac{1}{\sqrt{\sum_{k=1}^{K} |a_k|^2}} \cdot \frac{\sqrt{P_{RS} \cdot \Gamma_{RS,k} \cdot \Gamma_{MS,k}}}{\sigma_{RS,k} \cdot (\Gamma_{RS,k} + \Gamma_{MS,k} + 1)} \cdot e^{-j \cdot (\arg(h_{1,k}) + \arg(h_{2,k}))} \qquad (4)$$

It should be noted that $\Gamma_{RS,k}$ refers to the radio paths of the first link and $\Gamma_{MS,k}$ refers to the radio paths of the second link. Hence, the radio characteristics of both links are taken into account in each relay stations forwarding. $\Gamma_{RS,k}$ and $\Gamma_{MS,k}$ are preferably, but not necessarily calculated at each relay station.

The $\sum |a_k|^2$ term act as a power normalization factor, denoted φ, and it is observed that it cannot be determined individually by each relay. Instead it is hinted here that φ must be determined at some other suitable station and distributed to the relays. $1/\varphi$ corresponds to the common transmission parameter, and $\frac{\sqrt{P_{RS} \cdot \Gamma_{RS,k} \cdot \Gamma_{MS,k}}}{\sigma_{RS,k}^2 \cdot (\Gamma_{RS,k} + \Gamma_{MS,k} + 1)} \cdot e^{-j \cdot (\arg(h_{1,k}) + \arg(h_{2,k}))}$ to the relative transmission parameter for relay station k.

The maximum attainable receiver SNR under aggregate relay transmit power constraint can be determined to

$$\Gamma_{Eff}^{(\max)} = \sum_{k=1}^{K} \frac{\Gamma_{RS,k} \cdot \Gamma_{MS,k}}{\Gamma_{RS,k} + \Gamma_{MS,k} + 1} \tag{5}$$

At closer inspection, it is noted that the SNR contribution from each individual relay to $\Gamma_{Eff}^{(\max)}$ is equivalent to that if each relay station would transmit with all relay transmit power P_{RS} themselves.

Moreover, "derivation of analytic expressions", expressions for a combination of regenerative and non-regenerative coherent combining is also presented. When studying regenerative and non-regenerative coherent combining an interesting observation is that a regenerative approach is generally inferior to non-regenerative case, because regenerative relaying by necessity is constrained to a region around the transmitter and cannot exploit all available relays in an optimal manner. With other words, even though a signal may not be decoded, it may still contribute when coherent combining is employed. In any case, a combination of non-regenerative and regenerative scheme will perform slightly better than if only the non-regenerative method is considered. The mechanisms for power and phase control that are discussed in the following are is independent and generic to whether regenerative relaying is employed as well.

Phase control

As the first implementation example the logical architecture and the method according to the present invention is adapted for the use of facilitating coherent combining. A prerequisite for coherent combining is that signals are phase-aligned at the receiver. This is enabled by compensating for the complex phase from the transmitter 210 to the relay station 215 as well as the complex phase form the relay station 215 to the receiver 220. Practically, in each relay station the received signal, y_k, is multiplied with the phase factor $e^{-j \cdot \arg(a_k)}$ where $\arg\{a_k\} = -\arg\{h_{1,k}\} - \arg\{h_{2,k}\}$.

Therefore, explicit or implicit channel phase information must be made available at each individual relay station. There are essential two basic schemes that can be used in deriving phase information, one based on closed loop control and one on open loop control. The closed loop control is necessary to use when channel reciprocity cannot be exploited, such as in FDD (used over a single link), or when high control accuracy is required. The open loop control scheme instead exploits channel reciprocity, e.g. enabled by TDD (used over a single link)

with channel sounding that operates within channel coherence time. Open loop control is generally less accurate than closed loop control, due to asymmetries in the transmit/receive chains for a station. The differences boils down to the effort put into hardware design, and can always be compensated by improved design. Also, incorporating occasional closed loop control cycles may compensate for static open loop errors. However, in the present invention the phase error can in principle be up to ±90 degrees and still combine coherently (but not very efficiently) with other relayed signals. Hence, absolute phase accuracy is not a must, but certainly preferred. A closed control scheme generally relies on explicit signalling, reporting the result of measurements and therefore consumes more communication resources and incurs latency relative an open loop scheme. Note that this discussion on TDD vs. FDD considers duplexing technique over a single link at a time, e.g. the relay station to receiver link, whereas it is also possible to characterize the overall communication in the network on basis of time and frequency division. For example, link one and link two may share a frequency band or use different ones. From point of view of the invention, however, any combination of duplexing and multiple access schemes may be used, as long as channel phase information can be determined and used for phase compensation in the relay stations.

Tightly connected with closed loop and open loop control is the issue which station sends the pilots, which has been discussed previously in reference to *table 1*. Since it is the relay stations that must perform phase adjustment, this is the natural place to determine $\arg\{a_k\}$. If a relay station sends a pilot signal, the phase (or channel) parameters need to be reported back to the relay. This corresponds to the closed loop case. If a relay station instead receives a pilot, the phase (or channel) parameter does not need to be reported anywhere. This corresponds to the open loop case. It is clear that depending whether phase (i.e. channel) information need to be sent away in a control packet or can be kept in the same station, this has an impact on radio resource efficiency, power consumption as well implementation complexity. In any case, as seen form above, a myriad of possibilities exist and we select the most promising. A preferred combination of duplexing and multiple access will be further discussed. However, as appreciated by the skilled in the art a very large number of possibilities exist and the invention is not limited to the below exemplified.

Case one (see *table 1*), which is of open loop type and suitable for TDD with "sufficient" coherence time, offers the lowest signalling complexity as only two transmissions are necessary and the processing is distributed on all relay stations. Here, the transmitter as well as the intended receiver issue channel estimation symbols often enough or whenever needed

such that each relay can track both channels. The relay station subsequently estimates the channel phases that determine the phase factor of a_k.

Power control

A second important aspect for resource efficient communication, apart from phase control, is power control, since it provides means to ensure satisfactory communication quality. The logical architecture and the method according to the present invention is readily adapted to be used for an effective power control. The power control method is based on that the effective SNR at the receiver is controlled towards a target SNR, Γ_0, which assert the desired link quality. The target SNR may of course change with time depending on how link mode or QoS requirement changes with time. According to the logical architecture and the method according to the present invention power may be adjusted at the transmitter and individually at each relay. The relay power control has common as well as individual relay component. In the objective of minimizing the aggregate power addresses the issue of multiple access interference minimizations as well as minimizing relay power consumption. However, when a MS act as a transmitter, the power control may also be use as a method for significantly minimizing power consumption and radiated power for the MS, which among other advantages prolongs the battery life of the MS.

On the highest level, the power control problem may be defined as:

Find $\{P_{BS}, P_k\}$, $\forall k \in \{1,2,\ldots,K\}$; such that $\Gamma_{eff}^{(\max)} = \Gamma_0$

This is preferably accomplished under some constraints, such as minimization of $P_{RS} = \sum P_k$ and with fixed P_{BS}, but other constraints may also be considered, e.g. minimization of the total transmit power $P_{RS} + P_{BS}$ or by taking localization of relay induced interference generation into account. In the following, we assume minimization of $P_{RS} = \sum P_k$ with fixed (or relatively slow) adaptation of P_{BS}. This is a reasonable design objective in downlink, but for uplink it may be of greater interest to minimize the transmitter power. However, if the relays are mobile and relay on battery power, the sum power of relays and transmitter may be minimized.

This is the basic function of power control. From practical viewpoint, the overall task of controlling power in a cooperative relay network in general, and with coherent combining in

particular, is to use previous knowledge of used power P_{BS} and P_k and update those parameters to meet desired communication quality.

Power control share much of its traits with the phase control as the gain of the links may be estimated in several ways, depending on closed/open loop, TDD/FDD, distribution of control aspects. Hence, also here can a range of alternative implementations be envisioned. In the following, similar to the phase control discussion, it is assumed that the transmitter and receiver issue channel estimation signals and that channel gain reciprocity can be assumed, but the invention is not limited hereto.

The power control being proposed here has both a distributed component for each relay station, the relative transmission parameter, and a component common to all relays, the common transmission parameter. The scheme operates as follows: Through channel estimation, and with knowledge of the power used to send the pilot, each relay station may determine its respective path gain towards the transmitter and receiver respectively, but also interference and noise levels may be estimated at the same time. Based on path gain measurement, and information about P_{RS} and σ_{MS}^2, it is possible to determine $\Gamma_{MS,k}$. Possibly also based on path gain, noise with interference estimations and P_{BS} awareness, or simply direct SNR measurements on any received signal, the SNR at the relay station, $\Gamma_{RS,k}$, can be determined. Based on this, the relative transmit power levels can be determined at each relay station in a fully distributed manner. However, each relative transmit power level need to be scaled with normalization factor φ to ensure that aggregate transmit power is identical, or at least close, to the aggregate transmit power P_{RS}. This is the common power control part. If φ is too small, then more power than optimum P_{RS} is sent, and hence a more optimal relative power allocation exist for the invested transmit power. The same is valid when φ is too large. Hence, it is important for optimal resource investment to control φ such that the intended power P_{RS} is the aggregate transmit power level by the relays. N.B., it is not a significant problem from performance point of view if φ is somewhat to small as that only improves the effective SNR, since the relative impact of receiver internal noise is reduced.

Referring now to the logical architecture illustrated in FIG. 5 the normalization factor, being a common transmission parameter, is preferably determined, as well as distributed from, the receiver. This should be seen as a logical architecture, since it is also possible to forward all control information to the transmitter, which then redistribute it to the relay stations, fore

example. The first control loop 505 between the receiver 220 and the relay stations 215:k, provides the relay stations with the P_{RS}, whereas the second control loop 510 from the receiver 220 to the transmitter 210, provides the transmitter with P_{BS}. Optionally, if the transmitter has a better view of the whole radio system including many groups of cooperative TX-RS-RX links, similar to what a backbone connected basestation in a cellular system would have, then it may incorporate additional aspects that strive to optimize the whole system.

One method to implement the control loop at the receiver is now given, then assuming that P_{BS} is fixed (or controlled slowly). From a transmission, occurring at time denoted by n, the receiver measure the power of the coherently combined signal of interest, C_r, the relay induced noise measured at the receiver, N_r, and the internal noise in the receiver N_i. Based on this, and conditioned Γ_0, the receiver determines $P_{RS}^{(n+1)}$ and an update of a normalization factor, $\varphi^{(n+1)}$. This can be written as a mapping through an objective function f as

$$f(C_r, N_r, N_i) \rightarrow \{P_{RS}^{(n+1)}, \varphi^{(n+1)}\}; \text{ such that } \Gamma_{eff}^{(\max)} = \Gamma_0 \tag{6}$$

The receiver then distributed the updates, $P_{RS}^{(n+1)}$ and $\varphi^{(n+1)}$, to all relays through a multicast control message. To illustrate the idea, assume that P_{RS} is kept fixed from previous transmission, but the normalization factor is to be adapted. In the section "Derivation of analytic expression" it is shown that optimum normalization requires a balance between received signal, C_r, and the total received noise, interference and receiver internal noise $N_r + N_i$ according to

$$C_r = (N_r + N_i)^2 \tag{7}$$

Hence, by including the previous normalization factor $\varphi^{(n)}$, which is known by the receiver, and the update needed $\varphi^{(n+1)}$ to balance the equation, the relation becomes

$$C_r \frac{\varphi^{(n)}}{\varphi^{(n+1)}} = \left(N_r \frac{\varphi^{(n)}}{\varphi^{(n+1)}} + N_i \right)^2 \tag{8}$$

, which yields $\varphi^{(n+1)}$ by solving a simple second order equation.

If both P_{RS} and φ need to be updated, the balance equation above, the relation for the receiver SNR, Γ, can be used together with measured signal levels and solve for P_{RS} and φ. Linearization techniques, such as Taylor expansion and differentials, may preferably be used for this purpose and solving for ΔP_{RS} and $\Delta\varphi$.

It is noted that for the first transmission, the normalization factor is not given a priori. Different strategies may be taken to quickly adapt the power. For instance, an upper transmit power limit may initially be determined by each relay as they can be made aware of Γ_0 and also can determine their (coherent combining) SNR contribution. If each relay stays well below this upper limit with some factor, power can be ramped up successively by the control loop so ongoing communications are not suddenly interfered with. This allows control loops, for other communication stations, to adapt to the new interference sources in a distributed and controlled manner.

Also note that even though transmit power limitations occur in any relays, the power control loop ensures that SNR is maximized under all conditions.

Another, possibly more precise, method to determine the normalization factor is to determine the $|a_k|$ term in each relay and then send it to the receiver where $\sum|a_k|^2$, is calculated and hence yielding the normalization factor φ. Subsequently φ is distributed to all relays, similar to previous embodiment. Note that the amount of signalling may be reduced and kept on an acceptable level by sampling only a subset of all relays, i.e. some of the most important relays, in order to produce a sufficient good estimate of $\sum|a_k|^2$ term. This is further motivated that the $\sum|a_k|^2$ term will generally not change much over short time, even in fading channels, due to large diversity gains inherent in the invention.

Although power control has been described in the context of coherent combining, the framework is also applicable for power control in other types of relay cooperation schemes, such as various relay induced transmit diversity, such as Alamouti diversity. The framework is similar in that the power control considers combinations of transmitter power, individual relay power and aggregate relay power. Another example of relay induced transmit diversity is (cyclic/linear) delay diversity. Each relay imposes a random or controlled linear (or cyclic) delay on the relayed signals, and hence causes artificial frequency selectivity. Delay diversity is a well known transmit diversity from CDMA and OFDM based communication.

To summarize this section, this invention suggests using power control as a concept to ensure performance optimization for coherent combining based cooperative relaying in a realistic channel and in particular to optimize signal to noise ratio under aggregate relay transmit power constraints. This power control concept is not limited to coherent combining based cooperative relaying networks, but also other cooperative relaying oriented networks may use the same concept, though then with optimization objectives most suitable to the scheme being used. In addition, the basic features for a protocol based on channel sounding and estimation of gain parameters over both link one and link two are suggested. A reasonable design choice for protocol design (with commonalities with the phase control) has also been outlined, based on low complexity, low signalling overhead and low total power consumption. In particular, it is shown that combination of power control loops including relay and transmitter power control may be used. Lastly, it has been demonstrated that the control loop for the relays may be build on distributed power control decisions in each relay as well as a common power control part, where the whole set of relays are jointly controlled.

The main steps of the embodiment using the inventive method and architecture for efficient power control and phase control are illustrated in the flowchart of FIG. 6. The method comprises the steps of:

600: Send pilots on the *k* paths of link 1, from transmitter 210' to relay stations 215:*k*;

610: Each relay station 215:*k* estimates the *k* channel of link 1, $h_{1,k}$; Also interference and noise levels are estimated in order to calculate $\Gamma_{RS,k}$.

620: Send pilots on the *k* paths of link 2, from receiver 220' to relay stations 215:*k*;

630: Each relay station 215:*k* estimates its respective channel out of the *k* channel of 2, $h_{2,k}$;

640: Each relay station 215:*k* determines relative transmission parameters based on the channel estimates.

650: The receiver 220' determines a normalization factor φ.

660: The receiver 220' broadcast the normalization factor φ, P_{RS}, and σ_{RS}^2 to the relay stations 215:*k*.

670: Each relay station 215:k uses the broadcasted φ, P_{RS}, and the locally determined $\Gamma_{MS,k}$ and $\Gamma_{RS,k}$, and the phase of channel estimates $h_{1,k}$, $h_{2,k}$ to, on the reception of signal y_k, transmit the following signal:

$$z_k = y_k \cdot \frac{1}{\varphi} \cdot \frac{\sqrt{P_{RS} \cdot \Gamma_{RS,k} \cdot \Gamma_{MS,k}}}{\sigma_{RS,k} \cdot \left(\Gamma_{RS,k} + \Gamma_{MS,k} + 1\right)} \cdot e^{-j \cdot \left(\arg(h_{1,k}) + \arg(h_{2,k})\right)}$$

wherein the parameters $\Gamma_{RS,k}$ is calculated based on the channel estimate, P_{BS}, and σ_{RS}^2, and $\Gamma_{MS,k}$ based on P_{RS}, and σ_{MS}^2.

If the first transmission to the receiver is considered, (then the power loop is unaware of the forthcoming link quality), by way of example the relay may modify and upper limit the received normalization factor φ such that $\varphi_k = c \cdot |a_k|^2$, where $c \le 1$ being sent from the receiver or is a priori known.

675: The receiver 220' feedbacks control information to the transmitter 210' (P_{BS}).

The first control loop, indicated in step 660 may further comprise the substeps of:

660:1 The receiver measure at time n, the quality of the received signal, or more specifically the power of the coherently combined signal, C_r, the relay induced noise measured at the receiver, N_r, and the internal noise in the receiver N_i.

660:2 The receiver determines based on the measurement of step 675:1, and conditioned a desired Γ_0 target, an update of at least one of the normalization factor, $\varphi^{(n+1)}$ and the aggregate relay power $P_{RS}^{(n+1)}$.

660:3 The receiver distributed the updates, $P_{RS}^{(n+1)}$ and $\varphi^{(n+1)}$, to all relays through a multicast control message.

Similarly, the second control loop, indicated in step 675, may optionally comprise:

675:1 The receiver update the transmitter (BS) power $P_{BS}^{(n+1)}$.

Alternatively, if no estimations and calculations are to be done by the relay stations, unprocessed results of the pilots are forwarded to a centralized functionality, in the receiver for example, and relevant transmission parameters transmitted to each relay station.

Relay stations activation control

The method and architecture of the present invention may advantageously be used for deciding which relay stations 215:k to include in a communication, either at the establishment of the communication or during the communication session. As some relays experiencing poor SNR conditions on either link (transmitter-relay and relay-receiver) or both, they may contribute very little to the overall SNR improvements. Yet, those relays may still consume significant power due to receiver, transmitter and signal processing functions. It may also be of interest to have some control means to localize relay interference generation to fewer relays. Hence, it may therefore be considered to be wasteful to use some of the relay stations. Consequently, one desirable function is to activate relays based on predetermined criteria. Such criteria may be a preset lower threshold of acceptable SNR on either link, both links or the contribution to the effective SNR. The limit may also be adaptable and controlled by some entity, preferably the receiving station as it has information on momentary effective SNR. The relay may hence, e.g. together with power control information and cannel estimation symbols, receive a relay activation SNR threshold Γ_{Active} from the receiver to which the expected SNR contribution is compared against, and if exceeding the threshold, transmission is allowed, else not. The relay activation SNR threshold Γ_{Active} corresponds to a common transmission parameter, preferably determined by the receiver 220' and distributed to the relay station 215. The actual decision process, in which each relay station uses local parameters (corresponding to the relative transmission parameters) is distributed to the relay stations in the manner provided by the inventive method and architecture. This test, preferably performed in each relay prior to transmission, may e.g. be formulated according to:

$$\frac{\Gamma_{RS,k}\cdot(\Gamma_{RS,k}+1)\cdot\Gamma_{MS,k}^{2}}{\varphi^{(n+1)}\cdot(\Gamma_{RS,k}+\Gamma_{MS,k}+1)^{2}}\begin{cases}>\Gamma_{Active}\Rightarrow\text{Transmit}\\ \leq\Gamma_{Active}\Rightarrow\text{Silent}\end{cases}\tag{9}$$

, but other conditions, depending on relay methods including alternative relay diversity techniques, can also be used. For instance, the relay activation condition may more generally be characterized as an objective function f_2 according to $f_2(\Gamma_{RS,k},\Gamma_{MS,k})$.

Moreover, The broadcasted message containing the Γ_{Active} could further comprise fields that may be used to pinpoint specific relays (through assigned relay addresses) that should be incorporated, or is only allowed to be used, or must excluded or any combination thereof. Other methods to address certain relays may e.g. be based on address ranges. This enables one to limit the number of involved relays as desired.

From the above discussion and expression (9) it can be noted that the receiver 220' may, upon experiencing weakening SNR, for example due to the movement of the MS, choose to order a increased transmission power and/or to include more relay stations 215 by lowering the threshold Γ_{Active}. Other communication quality conditions, such as packet or bit error rate, may also be used by the receiver to trigger changes in the common parameters, such as a joint transmit power scaling of all relay powers.

Relay activation control may be incorporated in the power and phase control algorithm described with reference to FIG. 6, by modifying the steps 650-670, so that:

in 650: the receiver 220' also determines an activation SNR threshold Γ_{Active}

in 660: the receiver 220' also broadcast Γ_{Active} to the relay stations 215:*k*.

in 670: each relay station 215:*k* firstly determines if to broadcast using the activation SNR threshold Γ_{Active}, for example according to expression (9)

The method and architecture according the present invention may be adapted to other topologies than the above exemplified. The topology in FIG. 5 may, for example, be modified to include multiple antennas in each relay station as shown in FIG. 7. The benefit in doing that is that the number of relay stations can be reduced while still getting similar total antenna directivity gain. If each antenna element is separated more than the coherence distance, diversity gain is also provided. In all, this can reduce the cost, while providing near identical performance. However, reducing the number of relays may have a detrimental impact due to shadowing (i.e. log normal fading) and must be carefully applied. From signal, processing and protocol point of view, each antenna can be treated as a separate relay station. Another benefit of this approach is however that internal and other resources and may be shared. Moreover,

relaying may potentially be internally coordinated among the antennas, thereby mitigate interference generation towards unintended receivers.

The communication quality may be further improved by also incorporate the direct signal from the transmitter 210 to the receiver 220. There are at least two conceivable main methods to incorporate the signal from the transmitter. FIG. 8, depicts the topology when direct transmission from the transmitter is also considered.

In the first method, two communication phases are required. The receiver combines the signal received directly from the transmitter, in the first phase, with the relay transmission, from the second phase. This is somewhat similar to receiver based combining in the classical relay channel, but with coherent combining based relaying. Maximum ratio or interference rejection combining may be employed.

In the second method, Transmit-relay oriented Coherent Combining, only one communication phase is used, and used for coherent combining of the direct signal from the transmitter to the receiver with the relay signals. This can be made possible if relays can transmit and receive concurrently, e.g. over separated antennas. The phase of a_k must then ensure alignment of relayed signal with the direct signal as

$$\arg\{a_k\} = -\arg\{h_{1,k}\} - \arg\{h_{2,k}\} - \arg\{h_{BS,MS}\} + c_1$$

, where $h_{BS,MS}$ is the complex channel from the basestation to the mobile station. A consequence of incorporating the direct signal for coherent combining is that the relays must adaptively adjust their phase relative the direct signal. A closed loop can be used for this. Similar to the normalization factor power control, the receiver issues phase control messages to the whole group of relay stations, but with a delta phase θ to subtract from the calculated phase compensation $(-\arg\{h_{1,k}\} - \arg\{h_{2,k}\})$.

As the basestation does not induce any noise through its transmission, its transmit power does not need to be adjusted for optimal performance as was needed for the relays. Instead, performance increases monotonically with increasing basestation transmit power. One option is however to try to minimize the overall transmit power, aggregate relay power and basestation power. The parameter setting for this is similar to what has been derived in the discussion on regenerative relaying, assuming that the basestation is considered as a relay. In addition to above, multiple antenna elements at the transmitter may also be used, similar to the discussions on relays with multiple antennas.

The derivation of the relative and common transmission parameters is also directly applicable to multi carrier transmission, such as OFDM by handling each subcarrier independently. This will then include a common amplitude normalization, phase and distributed relay amplitude compensation per subcarrier. For doing this, the path over FFT-processing-IFFT is taken, or possible through time domain filtering. The power control may send a normalization factor φ and relay power indication P_{RS} in vector form to optimize performance per subcarrier. A more practical solution, is to send φ and P_{RS} as scalars, acting on all subcarriers. In case of subcarrier optimization, the power control may then try to minimize power the total transmit power over all subcarriers to meet desired communication quality. This then provides some diversity gain in the frequency domain.

Another OFDM aspect is that it is a preferred choice for the transmit-relay oriented Coherent Combining described above. The reason is that the cyclic prefix allow for some short relay transfer latency, where phase and amplitude is modified through a time domain filter enabling immediate transmission.

For single carrier transmissions, such as CDMA, and with frequency selective channels, a frequency domain operation similar to OFDM may be employed or optionally the phase alignment can be performed on the strongest signal path, or with a time domain filter as discussed for OFDM.

For coherent combining to work, it is important to synchronize relay station frequency to a common source. In a cellular system, the BS is a natural source as since the clock accuracy is generally better at the basestation than in any mobile station. This function can exploit the regular frequency offset compensation as performed in traditional OFDM receiver implementations, that mitigates inter channel interference.

However, the relays may optionally exploit GPS for frequency synchronization, if available.

While the invention has primarily been described in a context of coherent combining, the invention is not limited hereto. The invention may be applied on various types of existing and foreseen methods for 2-hop (cooperative) relaying. In the most general case, the transmit parameters of the relays are functions of communication characteristics of the first link, communication characteristics of the second link, or a combination thereof. The communication quality has been described outgoing from complex channel gain (suitable for coherent combining), however when other schemes are considered (offering diversity and/or spatial multiplex gains), other link characteristic metrics may be of more relevance. As an

example, for Alamouti diversity it may be more preferable to use average path gain metric ,G, instead of complex channel gains, h .

While the invention has been described in connection with what is presently considered to be the most practical and preferred embodiments, it is to be understood that the invention is not to be limited to the disclosed embodiments, but on the contrary, is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the appended claims.

Detailed derivation

In the analysis we assume that there are K relay stations arbitrarily located. Each relay station $k \in \{1,2,\ldots,K\}$ receives a signal composed of an attenuated version of the desired signal, e.g. modeled as complex Gaussian $x \sim N(0,1)$, as well as a noise plus interference term, $n_{RS,k}$, according to

$$y_k = h_{1,k} \cdot \sqrt{P_{BS}} \cdot x + n_{RS,k}$$

, where $h_{1,k}$ is the complex path gain from the basestation to relay station k and P_{BS} is the transmit power of the basestation.

In the relay, y_k is (for analytical tractability) normalized to unit power, and multiplied with a complex factor that generates output z_k. Subsequently z_k is sent over link two, towards the receiver and is on its way attenuated with complex path gain $h_{2,k}$, where it is super-positioned with signals from other relays and noise and interference is added.

As it is assumed that each relay normalize the received power plus noise to unit power prior amplification and phase adjustment, the relay transmit power constraint can be incorporated in the analysis by letting each station k use transmit power

$$P_k = \frac{P_{RS} \cdot |a_k|^2}{\sum_{k=1}^{K} |a_k|^2}$$

, where P_{RS} is the total transmit power of all relay stations, and a_k is a un-normalized complex gain factor for relay station k.

For aggregate power constrained relay transmission, the SNR at the receiver (Mobile Station, MS, assumed here) may then be written

$$\Gamma = \frac{\left| \sum_{k=1}^{K} \frac{\sqrt{P_{RS}} \cdot a_k}{\sqrt{\sum_{q=1}^{K} |a_q|^2}} \cdot \frac{h_{1,k} \cdot \sqrt{P_{BS}}}{\sqrt{|h_{1,k}|^2 P_{BS} + \sigma_{RS,k}^2}} \cdot h_{2,k} \right|^2}{\sum_{k=1}^{K} \frac{P_{RS} |a_k|^2}{\sum_{q=1}^{K} |a_q|^2} \cdot \frac{\sigma_{RS,k}^2}{|h_{1,k}|^2 P_{BS} + \sigma_{RS,k}^2} \cdot |h_{2,k}|^2 + \sigma_{MS}^2}$$

,where σ_{MS}^{2} is the noise plus interference level at the mobile station.

A condition for coherent combining is phase alignment of signals, which can be achieved by ensuring

$$\arg\{a_k\} = -\arg\{h_{1,k}\} - \arg\{h_{2,k}\} + c_1$$

, where c_1 is an arbitrary constant

The expression for the effective SNR resulting from coherent combining may then be rewritten as

$$\Gamma_{Eff} = \frac{\left|\sum_{k=1}^{K} |a_k| \cdot \frac{\sqrt{\Gamma_{RS,k}} \cdot \sqrt{\Gamma_{MS,k}}}{\sqrt{\Gamma_{RS,k}+1}}\right|^2}{\sum_{k=1}^{K} |a_k|^2 \cdot \frac{\Gamma_{MS,k}+\Gamma_{RS,k}+1}{\Gamma_{RS,k}+1}}$$

,where

$$\Gamma_{RS,k} = \frac{|h_{1,k}|^2 P_{BS}}{\sigma_{RS,k}^2}$$

,and

$$\Gamma_{MS,k} = \frac{|h_{2,k}|^2 P_{RS}}{\sigma_{MS,k}^2}$$

Note that $\Gamma_{MS,k}$ is a "virtual SNR" in the sense that it is the SNR if relay station k would use all aggregate relay stations transmit power by itself.

It is noticed that the SNR expression has the form

$$\Gamma_{Eff} = \frac{\left|\sum_{k=1}^{K} |a_k| \cdot c_{1,k}\right|^2}{\sum_{k=1}^{K} |a_k|^2 \cdot c_{2,k}}$$

which can be transformed by using

$$|b_k|^2 = |a_k|^2 \cdot c_{2,k}$$

, which yields

$$\Gamma_{Eff}=\frac{\left|\sum_{k=1}^{K}|b_k|\cdot\frac{c_{1,k}}{\sqrt{c_{2,k}}}\right|^2}{\sum_{k=1}^{K}|b_k|^2}$$

Now, the nominator is upper limited by Cauchy-Schwarz's inequality

$$\left|\sum_{k=1}^{K}|b_k|\cdot\frac{c_{1,k}}{\sqrt{c_{2,k}}}\right|^2\leq\sum_{k=1}^{K}|b_k|^2\cdot\sum_{k=1}^{K}\left|\frac{c_{1,k}}{\sqrt{c_{2,k}}}\right|^2$$

, hence for an optimal b_k equality can be attained and the resulting SNR is then

$$\Gamma_{Eff}^{(\max)}=\frac{\left|\sum_{k=1}^{K}|b_k|\cdot\frac{c_{1,k}}{\sqrt{c_{2,k}}}\right|^2}{\sum_{k=1}^{K}|b_k|^2}=\frac{\sum_{k=1}^{K}|b_k|^2\cdot\sum_{k=1}^{K}\left|\frac{c_{1,k}}{\sqrt{c_{2,k}}}\right|^2}{\sum_{k=1}^{K}|b_k|^2}$$

This may be conveniently expressed in SNRs as

$$\Gamma_{Eff}^{(\max)}=\sum_{k=1}^{K}\frac{\Gamma_{RS,k}\cdot\Gamma_{MS,k}}{\Gamma_{RS,k}+\Gamma_{MS,k}+1}$$

Through identification, it is seen that the maximum SNR can be attained if

$$|b_k|=Const\cdot\frac{c_{1,k}}{\sqrt{c_{2,k}}}$$

, where Const is an arbitrary constant that can be set to one for convenience.

From power control perspective, it is interesting to note that the nominator is exactly the square of the denominator for optimum SNR. This knowledge can therefore be used as a power control objective.

Using the reverse transformation, one yields

$$|a_k|=\frac{c_{1,k}}{c_{2,k}}$$

, or expressed in SNRs

$$|a_k| = \frac{\sqrt{\Gamma_{RS,k}} \cdot \sqrt{\Gamma_{MS,k}} \cdot \sqrt{\Gamma_{RS,k}+1}}{\Gamma_{RS,k}+\Gamma_{MS,k}+1}$$

Hence a relay receiving a signal y_k can determine z_k by determining

$$z_k = \frac{\sqrt{P_{RS}}}{\sqrt{\sum_{k=1}^{K}|a_k|^2}} \cdot \frac{e^{-j\cdot(\arg(h_{1,k})+\arg(h_{2,k}))} \cdot \sqrt{\Gamma_{RS,k}}\sqrt{\Gamma_{MS,k}}\sqrt{\Gamma_{RS,k}+1}}{\Gamma_{RS,k}+\Gamma_{MS,k}+1} \cdot \frac{y_k}{\sqrt{|h_{1,k}|^2 P_{BS}+\sigma_{RS,k}^2}}$$

$$= y_k \cdot \frac{1}{\sqrt{\sum_{k=1}^{K}|a_k|^2}} \cdot \frac{\sqrt{P_{RS}\cdot\Gamma_{RS,k}\cdot\Gamma_{MS,k}}}{\sigma_{RS,k}\cdot(\Gamma_{RS,k}+\Gamma_{MS,k}+1)} \cdot e^{-j\cdot(\arg(h_{1,k})+\arg(h_{2,k}))}$$

Regenerative relaying add-on

If the SNR at a relay station is high enough, the received signal may be decoded prior relaying the signal. To model this behavior, let's say that larger than a minimum SNR, Γ_{Decode}, is sufficient for decoding. The benefit in doing this, is that forwarding of detrimental noise (and interference) can be avoided all together, and hence result in a further enhanced SNR at the receiver. In this case however, the decoded signal should be phase compensated only for the second hop, i.e

$$\arg\{a_k\} = -\arg\{h_{2,k}\}$$

By setting $\sigma_{RS,k}^2 = 0$ for those stations in the previous expressions, one can derive the magnitude of the multiplicative factor $|a_k|$ as well as the contribution to the SNR improvement. The combination of both noise-free (regenerative) and noisy (non-regenerative) transmission then takes the form

$$\Gamma_{Eff}^{(\max)} = \sum_{k=1}^{K} \begin{cases} \dfrac{\Gamma_{RS,k}\cdot\Gamma_{MS,k}}{\Gamma_{RS,k}+\Gamma_{MS,k}+1} & , \text{ if } \Gamma_{RS,k} < \Gamma_{Decode} \\ \Gamma_{MS,k} & , \text{ if } \Gamma_{RS,k} \geq \Gamma_{Decode} \end{cases}$$

, and

$$|a_k| = \begin{cases} \dfrac{\sqrt{\Gamma_{RS,k}}\cdot\sqrt{\Gamma_{MS,k}}\cdot\sqrt{\Gamma_{RS,k}+1}}{\Gamma_{RS,k}+\Gamma_{MS,k}+1} & ,\text{if } \Gamma_{RS,k} < \Gamma_{Decode} \\ \sqrt{\Gamma_{MS,k}} & ,\text{if } V_{RS,k} \geq \Gamma_{Decode} \end{cases},$$

, and

$$\arg\{a_k\} = \begin{cases} -\arg\{h_{1,k}\} - \arg\{h_{2,k}\} & \text{, if } \Gamma_{RS,k} < \Gamma_{Decode} \\ -\arg\{h_{1,k}\} & \text{, if } \Gamma_{RS,k} \geq \Gamma_{Decode} \end{cases}$$

Note that $\Gamma_{RS,k} < \Gamma_{Decode}$ is only a model useful to assess performance in a mixed non-regenerative and regenerative relaying scenario. In practice, the upper expressions, .i.e. corresponding to $\Gamma_{RS,k} < \Gamma_{Decode}$, are used when the signal is not forwarded in a non-regenerative manner, and the lower expressions, .i.e. corresponding to $\Gamma_{RS,k} > \Gamma_{Decode}$, are used when the signal is not forwarded in a regenerative manner.

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CLAIMS

1. A method of performing communication in a two-hop wireless communication network, wherein a transmitter (210), a receiver (220) and at least one relay station (215) are engaged in a communication session, and the relay station (215) forwards signals from a first link between the transmitter (210) and the relay station (215) to a second link between the relay stations (215) and the receiver (220), **characterised in** that the forwarding performed by the at least one relay station (215) is adapted as a response to estimated radio channel characteristics of at least the first link.

2. The method according to claim 1, **wherein** the forwarding performed by the at least one relay station (215) is adapted as a response to estimated radio channel characteristics of both the first and second link.

3. The method according to claim 1 or 2, **wherein** the communication session involves a plurality of relay stations (215) and their respective forwarding is adapted based on a relative transmission parameter which is specific for each relay station and a common transmission parameter which is common to all relay stations.

4. The method according to claim 1, **wherein** the method comprises the steps of:
-*characterizing* (410, 430) the radio paths of the first and second link by the use of pilots;
-*determine* (440) at least one relative transmission parameter at least partly based on both of the channel estimates of each relay stations paths of the first and second link;
-*determine* (445) at least one common transmission parameter based;
-*distributing* at least said common transmission parameter to all relay station;
-*forwarding* (450; 450')the signal from the first link on the second link, wherein the forwarded signal is adapted based on each relay stations relative transmission parameter and the common transmission parameter.

5. The method according to any of claims 1 to 4, **wherein** the adaptation of the transmitted signal comprises an adjustment of phase.

6. The method according to any of claims 1 to 4, **wherein** the adaptation of the transmitted signal comprises an adjustment of transmission power.

7. The method according to any of claims 1 to 4, **wherein** the adaptation of the transmitted signal comprises an adjustment of transmission power and phase.

8. The method according to any of claims 1 to 7, **wherein** the adaptation of the transmitted signal comprises an adjustment of parameters relating to diversity.

9. The method according to of claims 8, **wherein** the adaptation of the transmitted signal comprises an adjustment of parameters relating to delay diversity.

10. The method according to of claims 8, **wherein** the adaptation of the transmitted signal comprises an adjustment of parameters relating to space time coded diversity.

11. The method according to any of claims 1 to 9, **wherein** the step of using the relay station's respective relative transmission parameter and the common transmission parameter(s) to adapt the subsequent transmissions on link 2, comprises to, on the reception of signal y_k, transmit the signal (670):

$$z_k = y_k \cdot \frac{1}{\varphi} \cdot \frac{\sqrt{P_{RS} \cdot \Gamma_{RS,k} \cdot \Gamma_{MS,k}}}{\sigma_{RS,k} \cdot \left(\Gamma_{RS,k} + \Gamma_{MS,k} + 1\right)} \cdot e^{-j \cdot \left(\arg(h_{1,k}) + \arg(h_{2,k})\right)}$$

wherein the parameters $\Gamma_{RS,k}$ and $\Gamma_{MS,k}$ are the locally determined relative transmission parameters based on the channel estimates $h_{1,k}$ and $h_{2,k}$, P_{BS} is the transmit power of the transmitter, σ_{RS}^2 is the noise and interference level at the relay station, P_{RS} is the aggregated transmit power from all relay stations, σ_{MS}^2 is the noise level at each receiver, and wherein the normalizing factor φ is a common parameter based on the total communication quality experienced by the receiver (220').

12. A relay station (215) adapted for use in a two-hop wireless communication network, wherein the network comprises a transmitter (210), a receiver (220) and at least one relay station (215), wherein the relay station (215) is adapted to forwarding signals from a first link between the transmitter (210) and the relay station(215) to a second link between the relay stations (215) and the receiver (220) **characterised in** that the relay station (215) is provided with means for adapting (218) the forwarding based on a characterization of at least the first link.

13. The relay station according to claim 14, **wherein** the relay station (215) adapt the forwarding as a response to estimated radio channel characteristics of both the first and second link.

14. The relay station according to claim 14, **wherein** the relay station (215) is further provided with means for performing channel characterization (216) and means for determining relative transmission parameters (217) based on the channel characterization, and the forwarding is at least partly based on said relative transmission parameters.

15. The relay station according to claim 15, **wherein** the relay station (215) is further provided with means for receiving a common transmission parameter, and the forwarding is at least partly based on said relative transmission parameters and said common transmission parameter

16. A system adapted for communication in a two-hop wireless communication network, wherein the network comprises a transmitter (210), a receiver (220) and at least one relay station (215), wherein the relay station (215) is adapted to forwarding signals from a first link between the transmitter (210) and the relay station(215) to a second link between the relay stations (215) and the receiver (220) **characterised in** that the relay station (215) uses characterization of at least the first link for the forwarding on the second link.

17. The system according to claim 16, **wherein** the relay station (215) adapt the forwarding as a response to estimated radio channel characteristics of both the first and second link.

18. The system according to claim 18, **wherein** the relay station (215) is further provided with means for performing channel characterization (216) and means for determining relative transmission parameters (217) based on channel characterization and the forwarding is at least partly based on said relative transmission parameters.

19. The system according to claim 17, **wherein** the system is provided with means for determining a common transmission parameter which is based on the total communication quality between the transmitter (210') and the receiver (220'), and the relay station (215) is further provided with means for receiving the common

transmission parameter and the forwarding on the second link is at least partly based on said relative transmission parameters and said common transmission parameter.

20. A receiver (220') adapted for use in a two-hop wireless communication network, wherein the network comprises a transmitter (210), the receiver (220) and at least one relay station (215), wherein the relay station (215) is adapted to forwarding signals from a first link between the transmitter (210) and the relay station (215) to a second link between the relay stations (215) and the receiver (220) **characterised in** that the receiver (220') is provided with means for determining at least one relative transmission parameter which is based on a characterization of at least the first link, and means for distributing said relative transmission parameter to the relay station.

21. The receiver (220') according to claim 20, **wherein** the determining means are adapted to determine a plurality of relative transmission parameter, one for each relay station (215) which are engaged in the communication session.

22. The receiver (220') according to claim 20 or 21, **wherein** the relative transmission parameter is based on characterisations of both the first and second link.

23. The receiver (220') according to any of claims 20 to 22, **wherein** the receiver i further provided with means for determining a common transmission parameter which is based on the total communication quality between the transmitter (210') and the receiver (220').

24. A base station adapted (210) for use in a two-hop wireless communication network, comprising a receiver (220') according to any of claims 20 to 23.

25. A mobile station (220) adapted for use in a two-hop wireless communication network, comprising a receiver (220') according to any of claims 20 to 23.

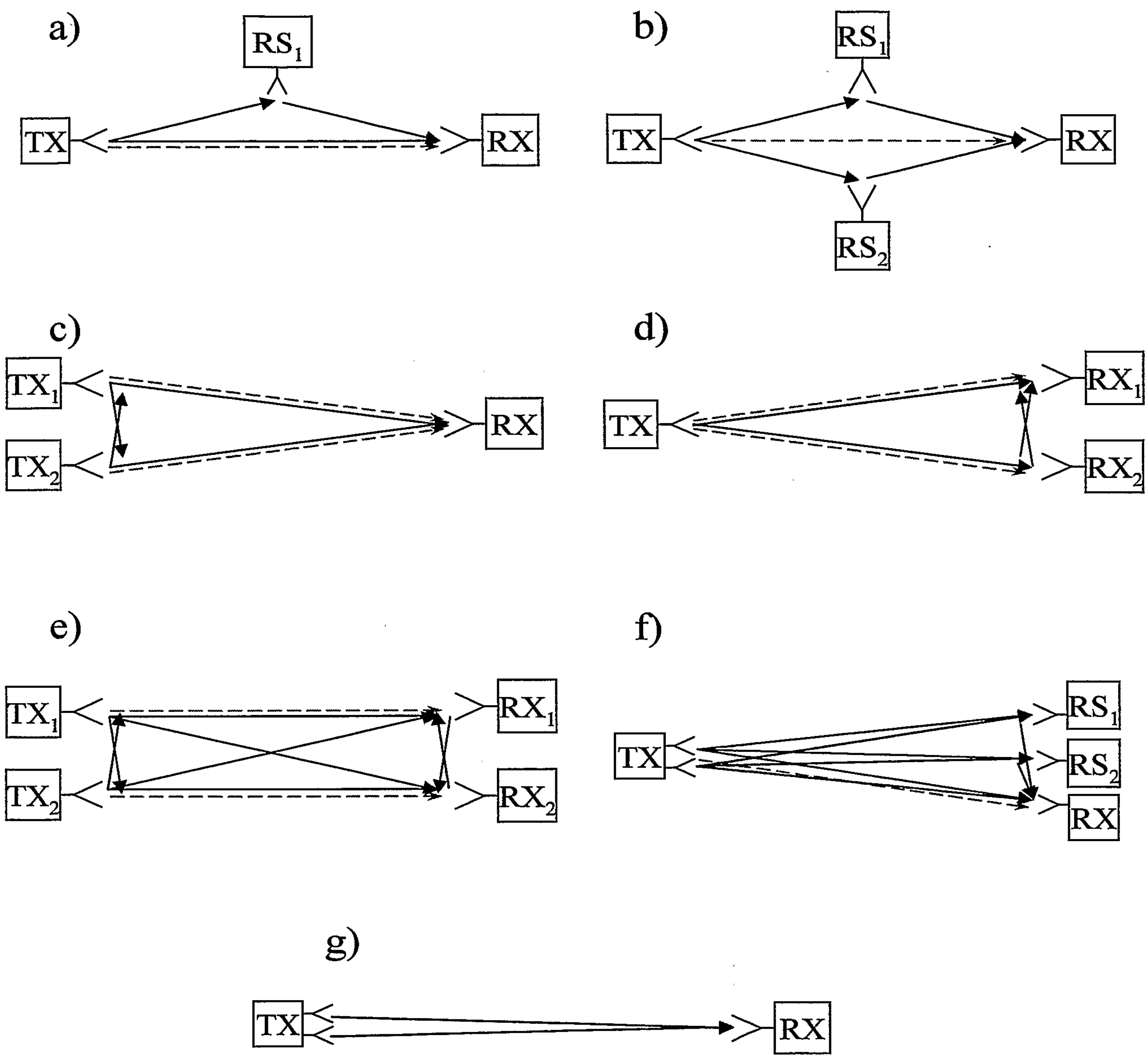

a)
RS1
TX
RX
b)
RS1
TX
RX
RS2
c)
TX1
TX2
RX
d)
TX
RX1
RX2
e)
TX1
TX2
RX1
RX2
f)
TX
RS1
RS2
RX
g)
TX
RX

Fig. 1

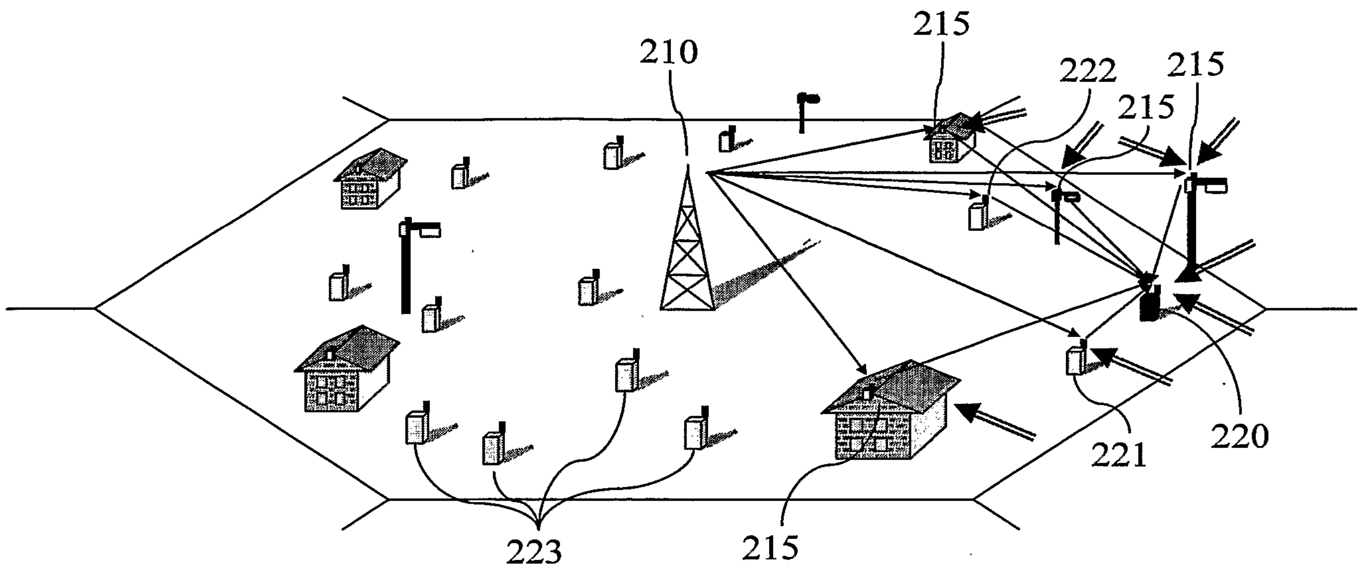
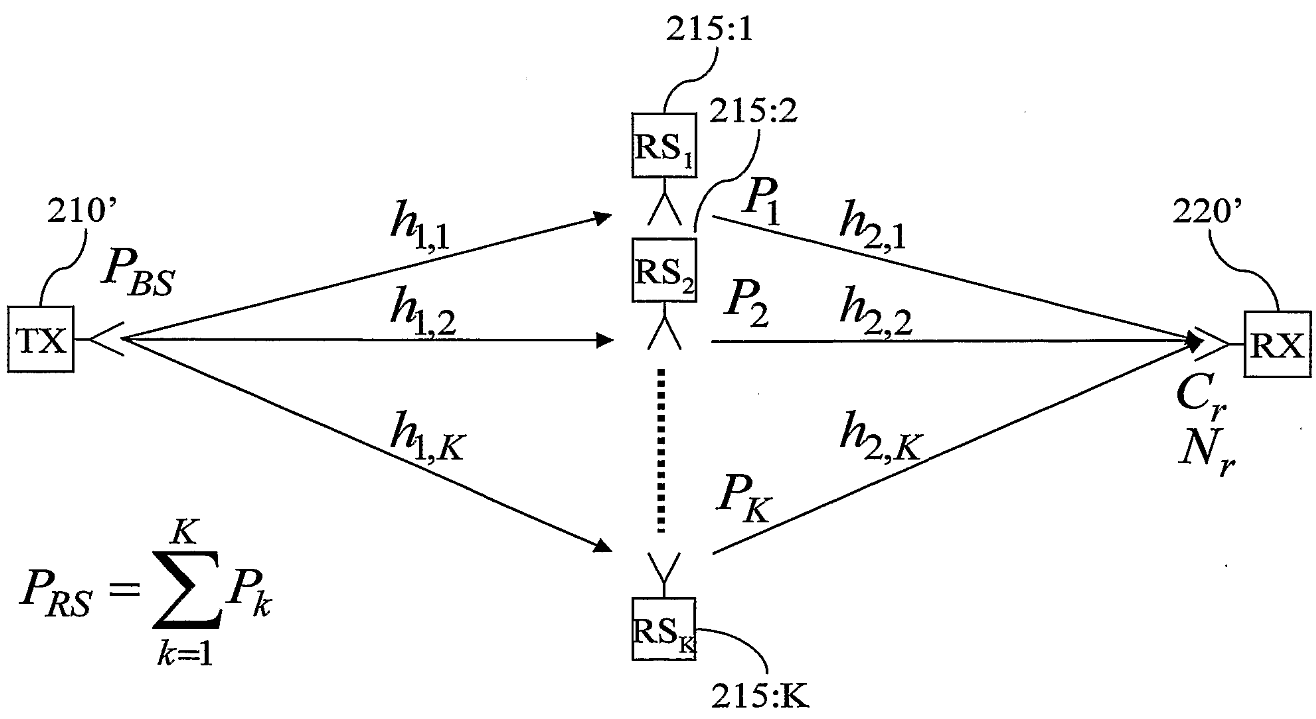


Fig. 2



$$P_{RS} = \sum_{k=1}^{K} P_k$$

Fig. 3

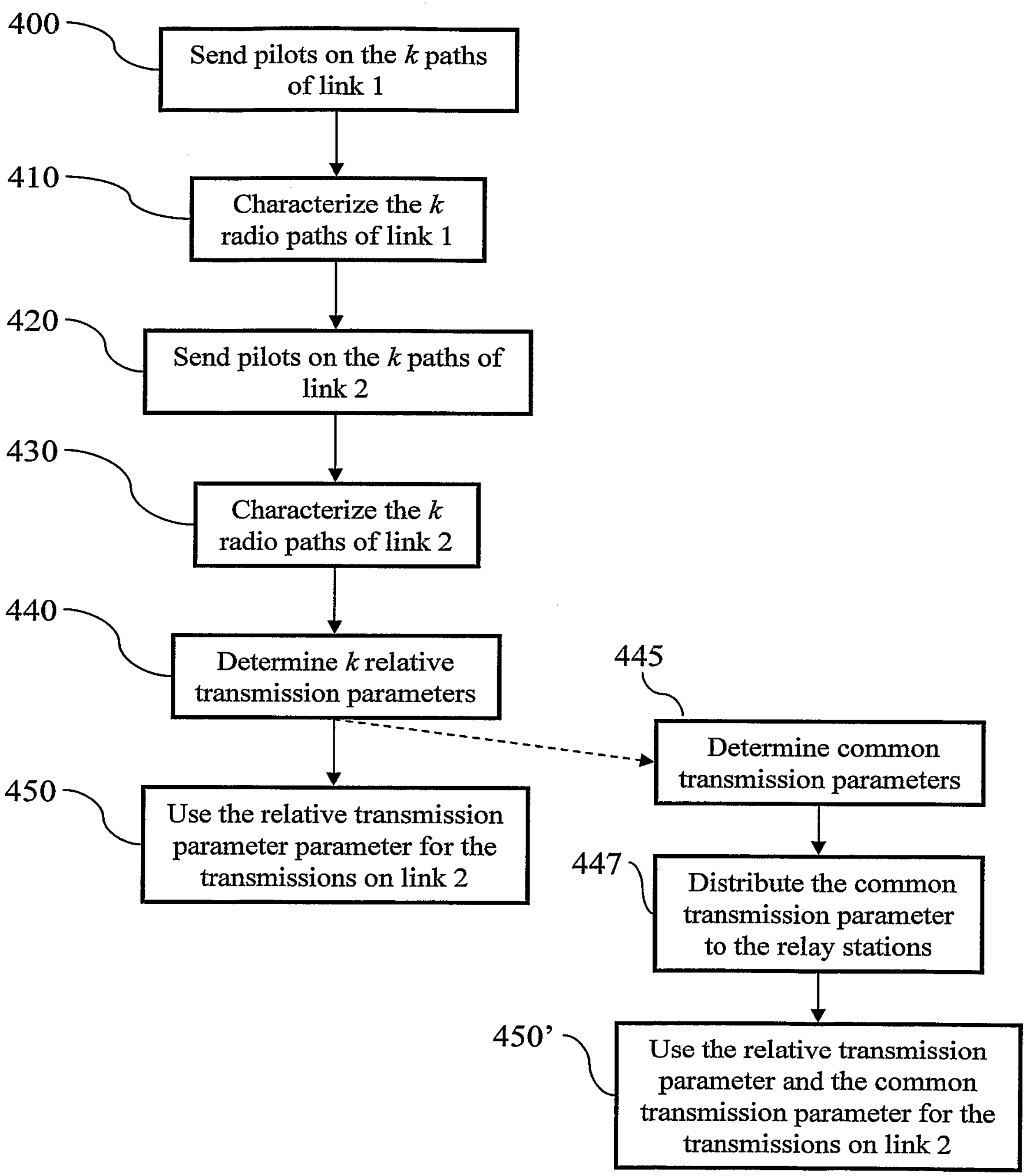

400
Send pilots on the k paths of link 1
410
Characterize the k radio paths of link 1
420
Send pilots on the k paths of link 2
430
Characterize the k radio paths of link 2
440
Determine k relative transmission parameters
445
Determine common transmission parameters
450
Use the relative transmission parameter parameter for the transmissions on link 2
447
Distribute the common transmission parameter to the relay stations
450'
Use the relative transmission parameter and the common transmission parameter for the transmissions on link 2

Fig. 4

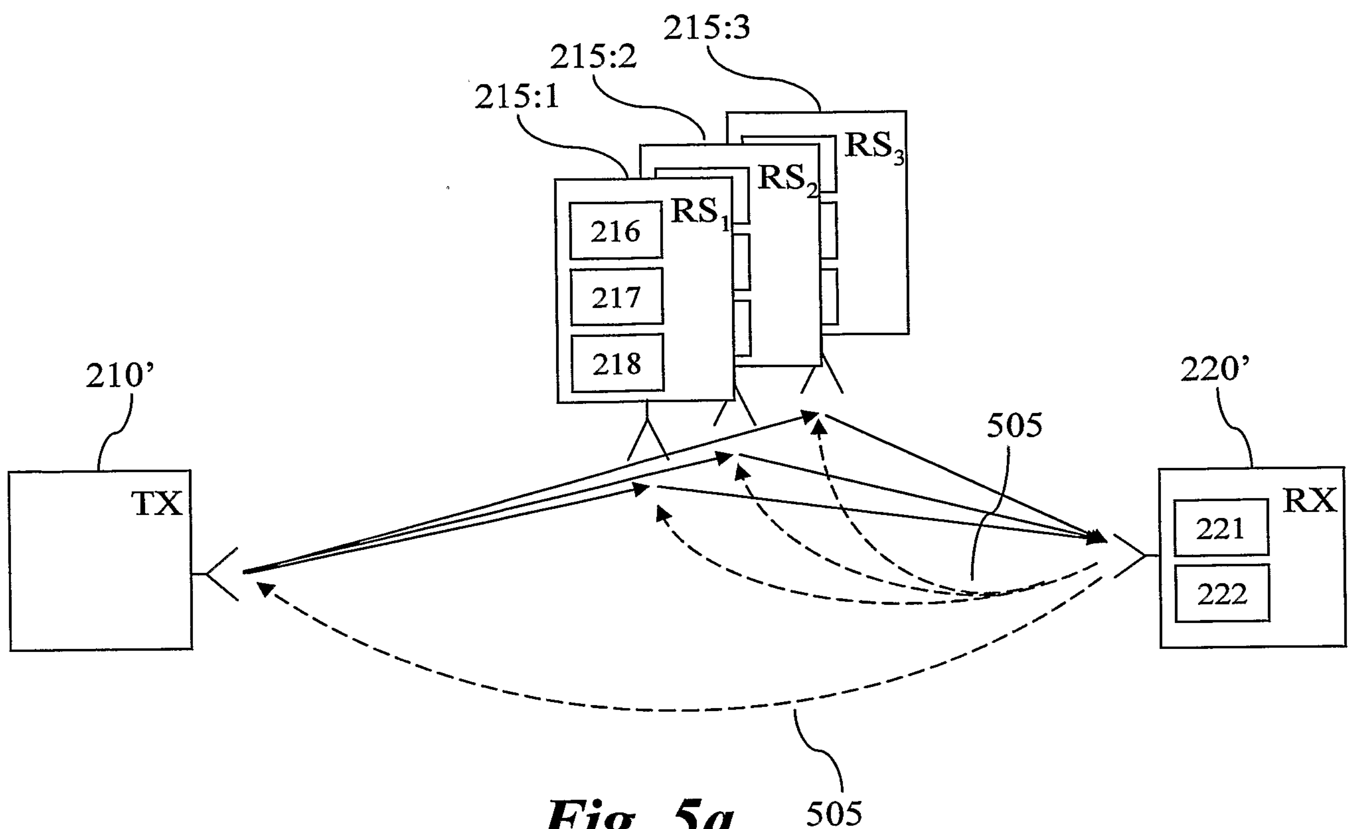

215:3
215:2
215:1
RS_3
RS_2
RS_1
216
217
218
210'
TX
505
220'
RX
221
222
505

Fig. 5a

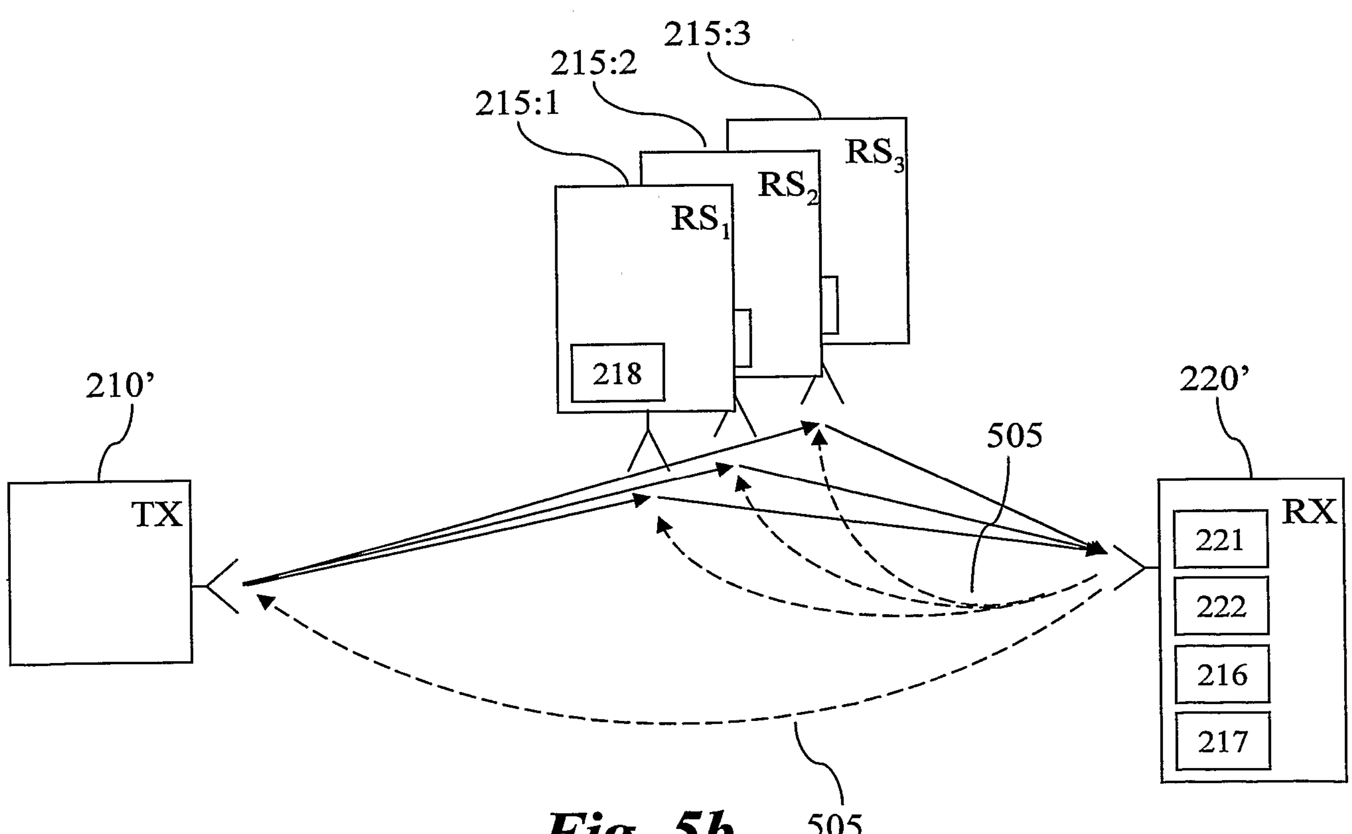

215:3
215:2
215:1
RS_3
RS_2
RS_1
218
210'
TX
505
220'
RX
221
222
216
217
505

Fig. 5b

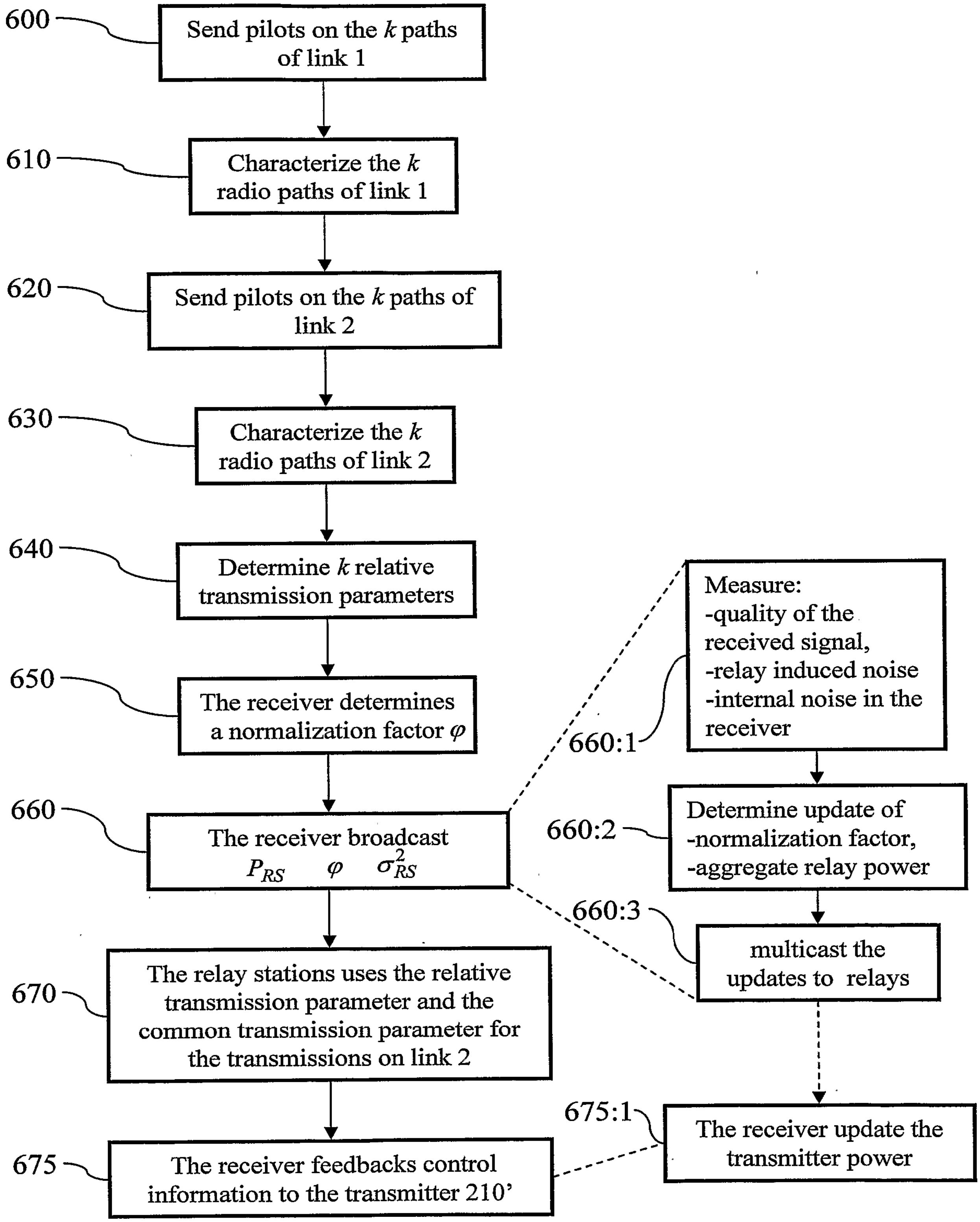

600
Send pilots on the k paths of link 1
610
Characterize the k radio paths of link 1
620
Send pilots on the k paths of link 2
630
Characterize the k radio paths of link 2
640
Determine k relative transmission parameters
650
The receiver determines a normalization factor φ
660
The receiver broadcast P_{RS} φ σ^2_{RS}
670
The relay stations uses the relative transmission parameter and the common transmission parameter for the transmissions on link 2
675
The receiver feedbacks control information to the transmitter 210'
660:1
Measure:
-quality of the received signal,
-relay induced noise
-internal noise in the receiver
660:2
Determine update of
-normalization factor,
-aggregate relay power
660:3
multicast the updates to relays
675:1
The receiver update the transmitter power

Fig. 6

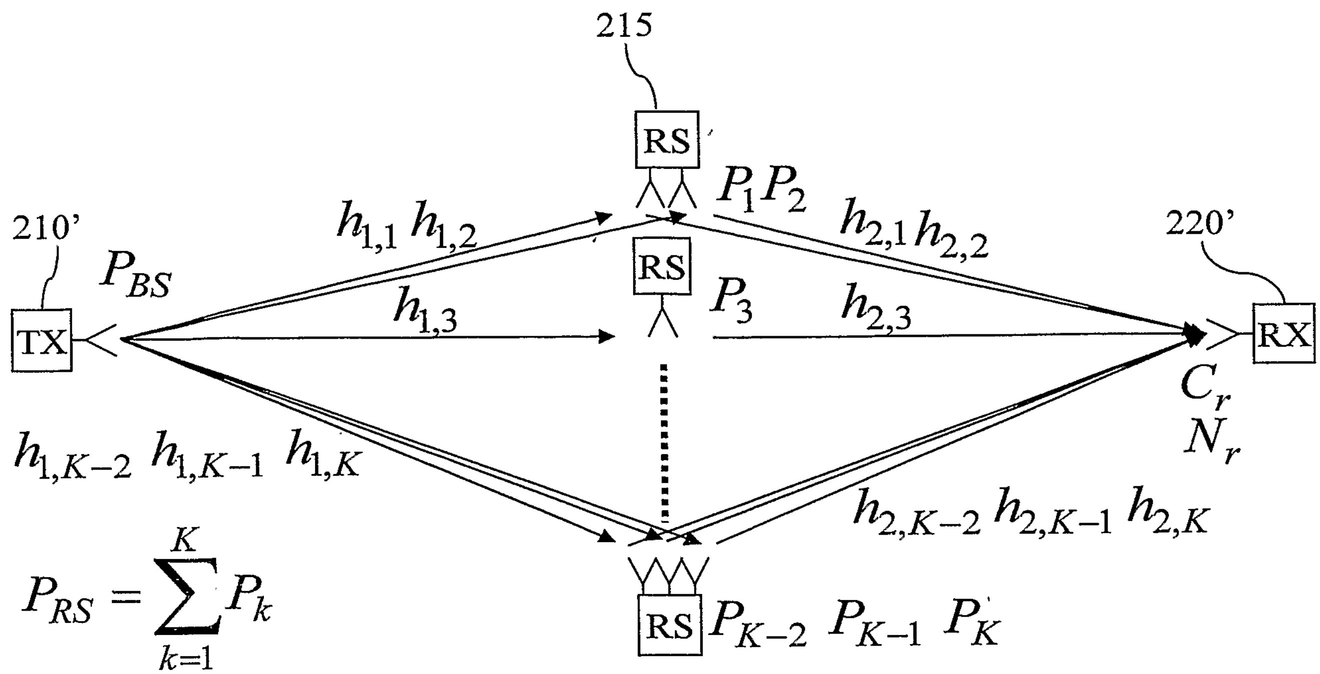

215
RS
$P_1 P_2$
210'
$h_{1,1}\ h_{1,2}$
$h_{2,1}\ h_{2,2}$
220'
P_{BS}
RS
P_3
TX
$h_{1,3}$
$h_{2,3}$
RX
C_r
N_r
$h_{1,K-2}\ h_{1,K-1}\ h_{1,K}$
$h_{2,K-2}\ h_{2,K-1}\ h_{2,K}$
$P_{RS} = \sum_{k=1}^{K} P_k$
RS
$P_{K-2}\ P_{K-1}\ P_K$

Fig. 7

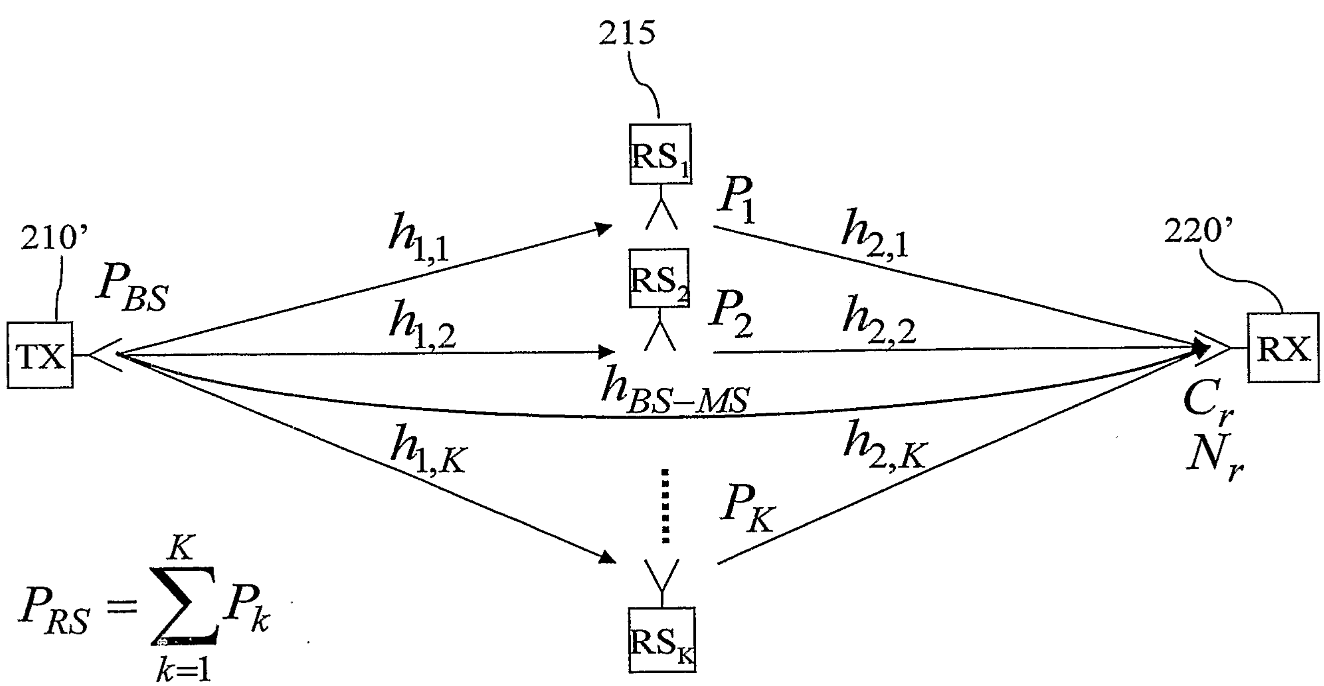

215
RS_1
P_1
210'
$h_{1,1}$
$h_{2,1}$
220'
P_{BS}
RS_2
P_2
TX
$h_{1,2}$
$h_{2,2}$
RX
h_{BS-MS}
C_r
N_r
$h_{1,K}$
$h_{2,K}$
P_K
$P_{RS} = \sum_{k=1}^{K} P_k$
RS_K

Fig. 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 2004/000825

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: H04L 25/52, H04B 7/14, H04Q 7/32

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: H04B, H04L, H04Q

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-INTERNAL, WPI DATA, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2002039383 A1 (ZHU, J ET AL), 4 April 2002 (04.04.2002), paragraphs [0005]; [0076] - [0085], abstract --	1,2,5-10, 12-14,16-18
X	WO 0233996 A1 (SPOTWAVE WIRELESS INC), 25 April 2002 (25.04.2002), page 3, line 7 - line 16; page 8, line 18 - page 9, line 21, abstract --	1,2,5-10, 12-14,16-18
A	LANEMAN, J N et al: Energy-efficient antenna sharing and relaying for wireless networks. XP010532457, 2000-09-23. See section I, figure 1, abstract -- --------	1-25

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
8 Sept 2004	13-09-2004

Name and mailing address of the ISA/	Authorized officer
Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Ralf Boström /LR Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 2004/000825

US	2002039383	A1	04/04/2002	SG	99310	A	27/10/2003
WO	0233996	A1	25/04/2002	AU	1029902	A	29/04/2002
				CA	2323881	A	18/04/2002
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				EP	1327369	A	16/07/2003
				US	2002044594	A	18/04/2002
				US	2002045431	A	18/04/2002
				US	2002045461	A	18/04/2002
				US	2004097189	A	20/05/2004